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14. ABSTRACT The Wireless Communications Laboratory (WCL) at Ohio State University has been built up with an RF fading channel emulator, base station mobile units and computational engines, that are integral to the establishment of a state-of-the-art wireless test-bed for Code Division Multiple Access research. These components are being used rigorously to test Code-Division Multiple Access communication. The equipment enhancements have enabled a real-time system, based on "software radio" to replace off-line data manipulation experiments. This next theoretical/experimental stage is critical and progress is being achieved through exploiting very specific wireless characteristics.					
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1. OBJECTIVES

We defined and we pursued a novel line of research that lies in a multidisciplinary intersection of Estimation Theory, Communications Theory, and Mean-Square optimum linear filtering. Consider an arbitrary input signal vector space and a given information bearing signal vector to be protected or recovered in the presence of multiuser or other forms of heavy interference. Based strictly on statistical conditional optimization principles, we developed an iterative algorithm that starts from the conventional matched-filter correlator and generates a sequence of linear filters ("auxiliary-vector" filters) that converges to the exact MS-optimum solution. At each iteration step, the filter is given as a direct function of the input autocorrelation matrix, the signal vector waveform to be protected, and the filter at the previous iteration. When the autocorrelation matrix is sample-average estimated from a short data record, this procedure offers the means for effective control over the filter estimator bias versus (co-)variance trade-off. For a fixed data record size the filter estimators in this sequence have rapidly decreasing bias and slowly increasing variance. They outperform other known estimators such as Sample-Matrix-Inversion (SMI), Diagonal-Loading (DL) SMI, RLS, LMS, reduced-rank eigenvector decomposition and "multistage" nested Wiener filter. While all of the above estimators converge to the optimum MMSE/MVDR solution for infinitely long data record, for any given finite data set there is at least one AV filter estimator in the sequence that outperforms the SMI, DL-SMI, RLS, LMS, reduced-rank eigenvector decomposition as well as the multistage nested Wiener filter.

Finally, we looked at the problem of binary code design. Although this investigation is at an initial stage, our theoretical developments so far advanced the prior-state-of-the-art in the context of fundamental binary code design for code division signal multiplexing. We developed novel, doubly optimal designs of minimum total-squared-correlation (TSC) and minimum maximum-squared-correlation (MSC) binary codes and we pursued theoretical analysis of the codes and application for interference avoidance at the transmitter-end of a communication link.

2. SUMMARY OF RESEARCH EFFORT

The milestones reached during the duration of this research project

(2 years) are as follows.

(i) We addressed successfully the problem of determining an automated theoretically derived rule for the selection of the best number of auxiliary vectors for a given data record of input observations.

(ii) We developed a recursive algorithm for the on-line estimation of the AV filter and a modified RLS-type algorithm for the estimation of the MMSE/MVDR filter that are both based on the interference-plus-noise covariance matrix estimate and we established formally their convergence properties.

(iii) We investigated theoretically the coarse synchronization performance of blind adaptive linear self-synchronized receivers for asynchronous direct-sequence spread-spectrum communications under finite data record adaptation. We derived analytical expressions that approximate the probability of coarse synchronization error of matched-filter-type (MF) and minimum-variance-distortionless-response-type (MVDR) receivers based on transformation noise modeling techniques.

(iv) We studied theoretically the data-record-size requirements of MMSE/MVDR-type adaptive algorithms to meet a given performance objective in joint space-time signal detection and direction-of-arrival (DoA) estimation problems for direct-sequence spread-spectrum systems. We derived closed form expressions that provide the data record size that is necessary to achieve a given performance confidence level in a neighborhood of the optimal performance point, as well as expressions that identify the performance level that can be reached for a given data record size.

(v) As an application of great importance to AFRL, we addressed the problem of navigation data demodulation by an adaptive GPS receiver that utilizes a bank of single-satellite linear-tap-delay filters and employs antenna-array reception.

3. ACCOMPLISHMENTS/NEW FINDINGS

Selecting the most successful (in some appropriate sense) AV filter estimator in the generated sequence for a given data record was a problem that had not been addressed so far. We dealt exactly with this problem and we proposed two data driven selection criteria [1], [2], [3]. The first criterion is specific to digital communications (binary hypothesis testing) and maximizes the estimated J-divergence of the AV-filter output conditional distributions given the transmitted information bit. The second criterion applies to all filter estimation problems and minimizes the cross-validated sample average variance of the AV-filter output.

We observed that the presence of the desired signal during estimation of the minimum-mean-square-error (MMSE)/minimum-variance-distortionless-response (MVDR) and auxiliary-vector (AV) filters under limited data support leads to significant signal-to-interference-plus-noise ratio (SINR) performance degradation. We quantified this observation in the context of DS/CDMA communications by deriving close approximations for the mean-square filter estimation error, the probability density function of the output SINR and the probability density function of the symbol-error-rate (SER) of the sample-matrix-inversion (SMI) receiver evaluated using both desired-signal-present and desired-signal-absent input covariance matrix. To avoid such performance degradation we proposed a DS/CDMA receiver that utilizes a simple pilot-assisted algorithm that estimates and then subtracts the desired signal component from the received signal prior to filter estimation. Then, to accommodate decision directed operation we developed two recursive algorithms for the on-line estimation of the AV and MMSE/MVDR filter and we studied their convergence properties [4].

We also investigated the data-record-size requirements of minimum-variance-

distortionless-response-type adaptive algorithms to meet a given performance objective in joint space-time signal detection and direction-of-arrival (DoA) estimation problems for direct-sequence spread-spectrum systems. We derived closed form expressions that provide the data record size that is necessary to achieve a given performance confidence level in a neighborhood of the optimal performance point, as well as expressions that identify the performance level that can be reached for a given data record size [7]. This was done by utilizing close approximations of the involved probability density functions. The practical significance of the derived expressions lies in the fact that the expressions are functions of the number of antenna elements and the system spreading gain only, while they are independent of the ideal input covariance matrix which is not known in most realistic applications.

In the presence of additive white Gaussian noise (AWGN), complete elimination of the spread-spectrum interference introduces enhanced noise variance at the decorrelator's output. (Noise variance enhancement at the decorrelator's output refers to the filtered noise variance experienced at the output of a decorrelator that is distortionless in the direction of a given user-signature of interest as it compares to the noise variance at the output of the corresponding MF). It was observed, however, that at times a partial decorrelator (PDEC) can strike an improved balance between interference suppression and noise enhancement when compared to the full decorrelator (DEC) while maintaining a decorrelating structure. That is, instead of decorrelating the complete multiple-access-interference (MAI) in the system, the PDEC chooses purposefully to decorrelate only a part of the MAI so that it exhibits a higher output signal-to-interference-plus-noise-ratio (SINR) than the full DEC. We understand that when unknown interference is present in the system, decorrelating receivers may operate unintentionally under partial decorrelating conditions. We identified necessary and sufficient conditions on the signal energy and signature cross-correlation levels under which the PDEC outperforms the full DEC in the output SINR sense, and we showed why decorrelation of interferers that satisfy such conditions should be purposefully avoided if at all possible [9], [10].

We considered the problem of binary signature set design for DS-CDMA users that transmit over multipath fading channels. First, we considered the problem of selecting optimally the signature of a single user in the presence of spread-spectrum interference (MAI), inter-symbol-interference (ISI) due to the multipath channel, and background noise. The signature is chosen to maximize the output SINR of the ("maximum-SINR") RAKE/MMSE filter. Since optimum binary signature selection has complexity exponential in the processing gain of the system, we proposed [15] a suboptimum computationally efficient algorithm based on the Cholesky decomposition method. The proposed algorithm optimizes the coordinates of the user signature conditionally and is characterized by linear complexity. Finally, we generalized this approach to cover the system-wide multiuser signature set selection problem, where each user's signature is adjusted iteratively according to the above algorithm. The performance of this scheme was evaluated through simulations where we initialized the algorithm at an arbitrary signature set and we observed its convergence to a new signature set for which the output SINR of each user's RAKE/MMSE filter is significantly increased.

Finally, we developed a new multiuser detection algorithm in the context of asynchronous AWGN multiple-access channels [18], [19]. A decorrelating or MMSE/AV multiuser filter is used as a pre-processor that provides initial decisions and reliability measurements based on which an ordered error pattern sequence of tunable length is formed. The error pattern sequence is followed to its end and the most likely bit vector among all visited options is returned. When the length of the pattern sequence is of the order of the number of bits to be detected, the additional imposed computational cost compared to straight decorrelating or MMSE/AV detection is rather insignificant. Still, we saw that this proposed multiuser detection algorithm maintains near-ML bit-error-rate performance over the whole studied SNR range of interest. There is strong

- resemblance between this scheme and ``efficient'' decoding algorithms for binary linear block codes [20].

4. PERSONNEL INVOLVED IN EQUIPMENT IMPLEMENTATION

Faculty:

U. Mitra

M. Fitz

5. PUBLICATIONS

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